Representative Charting of Vital Signs in an Intensive Care Unit

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ABSTRACT

An automatic vital signs charting system had been operational in the intensive care units of our hospital for over 10 years, but the system was susceptible to non-representative transients in the data. A median selection rule was implemented to make the system less susceptible to transients. After implementation of the median rule, we examined (1) the agreement of the resulting medians and the values that would have been reported using the previous "real-time" system and (2) the frequency of occurrence of "out-of-range" values for each system. The median value system was found to improve the representativeness of the recorded data. Improved representativeness will enhance the usefulness of reports, but more importantly will enable us to use the resulting data as inputs to computerized practice protocols and other computerized decision support applications.

INTRODUCTION

Patients in the intensive care unit (ICU) and in surgery present a monitoring paradox. On one hand, their condition calls for frequent and timely vital sign reporting. On the other hand, their condition also requires constant vigilance by the caregiver (a nurse, anesthesiologist, respiratory therapist, etc.). Unfortunately, it is difficult for a caregiver to be both a frequent, timely vital signs charter and a constant, careful observer. What most often occurs is that both the charting and the vigilance suffer -- the charting is not always timely or frequent when the caregiver attends to other duties, and the vigilance is sometimes intruded upon when the caregiver attends to charting. Automated charting of vital signs presents a solution to the paradox. Automated charting has been observed to improve timeliness, accuracy, legibility, and completeness of the patient record in anesthesia [1-3] and similar benefits are expected in the ICU [4].

Automatic charting must not only be frequent and timely, but of course must also be accurate. Simply sampling a patient monitor's output at regular intervals allows for the possibility that a transient event may occur at the sampling time. The result is the acquisition of non-representative data. "Non-representative" will be defined herein as not accurately depicting the parameter's central tendency during a given period. A non-representative value need not be non-physiological (i.e., caused by some problem in the monitoring process such as flushing the catheter, drawing blood, etc.). A non-representative value may in fact be an accurate representation of a true, albeit fleeting, physiological state. However, we assume that the goal of an automatic charting system is *routine* charting, not *exception* charting. *Routine* charting periodically reports physiological parameters to illustrate relatively long-term trends. *Exception* charting, on the other hand, involves detecting and recording specific, clinically important events that can sometimes be very short-lived.

Reports that search the database and decision support applications that use the data as inputs can be rendered untrustworthy by non-representative data. A solution to the problem of non-representative data is to chart a measure of central tendency instead of the actual value. In the ICUs at LDS Hospital in Salt Lake City, we have implemented a vital signs charting system that automatically charts median values every 15 minutes.

METHODS

For over 20 years, clinicians at LDS Hospital have used the Health Evaluation through Logical Processing (HELP) clinical information system [5]. The main feature of the HELP system is a centralized patient database located on a Tandem mainframe computer. The database receives inputs from many departments and ancillary services throughout the hospital. Automatic monitoring of vital signs in the ICUs is one of those many inputs..

Each ICU has a Charles River Data Systems minicomputer that receives data from Marquette patient monitors. "C"-based software on the minicomputer originally sampled the patient monitors in "real-time" every 15 minutes, on the quarter hour. Systolic, diastolic, and mean arterial blood pressures; heart rates; and core temperatures were the five parameters included in the sampling. The sampled data were then transferred to the patient database on

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the Tandem/HELP System.

The system provided timely data but was vulnerable to non-representative transients, even though the patient monitor itself performed some filtering before the minicomputer sampled its output [6]. In turn, the 24-hour Rounds Report was especially sensitive to non-representative data. The Rounds Report selected a patient's minimum and maximum blood pressure values from the past 24-hours. If just one extremely high or low non-representative value occurred during the 24 hours, it would be selected as the high or low. Instead, physicians in the unit wanted to see the minimums and maximums from "routine reporting" data, disregarding minimums and maximums of episodic events.

Furthermore, and more importantly, non-representative data were preventing us from using automatically collected blood pressure values in computerized decision support applications. APACHE acuity scoring had existed in computerized form for several years, but had fallen into disuse largely because of unreliability in its blood pressure input values. Also, LDS Hospital investigators were developing computerized protocols designed to standardize medical care. Protocol developers at the hospital have observed that an important requirement for computerized protocols is accurate, timely data [7,8]. Thus, reliable, automatic blood pressure data acquisition and charting was a fundamental building block of our medical informatics efforts in the ICU.

To ameliorate the problem of non-representative data, a new automatic recording scheme was devised. The "pilot" unit to implement the scheme was LDS Hospital's Shock/Trauma/Respiratory Intensive Care Unit (STRICU). The unit is a level 1 regional trauma referral center that employs four attending MD intensivists. It treats critically ill trauma, respiratory, multisystem organ failure, and postoperative liver transplantation patients. The unit provides treatment for one to two patients per registered nurse and has 24-hour physician coverage. Eighty to ninety percent of STRICU patients have arterial lines, permitting continuous vital signs monitoring.

The software on the unit's minicomputer was modified to sample the five vital signs from the Marquette monitor every three minutes instead of every 15 minutes. Every three minutes was the practical sampling limit imposed by polling the 12 rooms in the ICU. The minicomputer software was further modified to select a median every quarter hour for each of the five sampled parameters. Medians were selected from the most recent 15 minutes of collected data. On every quarter hour, the *medians* were transmitted to the HELP patient database instead of the actual, "real-time" values.

To evaluate the new system, files containing both the quarter-hour medians and the actual real-time values were kept on the minicomputer in July and August of 1993. The median values calculated on the quarter-hour were compared with the actual values occurring at the quarter-hour (the values that would have been recorded by the "real-time" system). We assumed that in most cases, there should be close agreement between the 15-minute median and the actual quarter-hour value. Cases in which there was a large disparity between the median and the actual value (> 30 mm Hg for blood pressures or > 30 beats per minute for heart rate) were examined individually to determine if the median was a representative value for the given time period.

"Out-of-range" values were also addressed. Data values were considered to be "out-of-range" according to criteria set forth by hospital physicians. The criteria are listed in Table I. "Out-of-range" temperature values were not found to be a problem and therefore were not considered in the comparison. Mean arterial pressures were not compared since they are a function of systolic and diastolic pressures.

The frequency of occurrence of "out-of-range" data under the "real-time" automatic system was compared with the frequency of occurrence under the median system. Until recently, nurses also routinely charted blood pressures and heart rate manually in the HELP system. Therefore, the frequency of occurrence of "out-of-range" data entered manually by nurses was also compared.

Table I. Definitions of "out-of-range" values for systolic and diastolic pressure and heart rate.

Parameter	Out-of-range definition
Systolic Pressure	<90 or > 220 mm Hg
Diastolic Pressure	<30 or >140 mm Hg
Heart Rate	<20 or >200 bpm

To find "out-of-range" values generated by the "real-time" automatic system, the HELP patient database was searched from July 29, 1993 to August 8, 1993. To find "out-of-range" values generated by the median system, the database was searched from August 31, 1993 to September 10, 1993. To find "out-of-range" values generated by nurse charting, the database was searched from June 12, 1993 to August 24, 1993. The search interval for manually-charted data was larger than for automatically-charted data because nurses only charted every 2 hours, as opposed to the automatic systems which charted every 15 minutes. A larger search interval was necessary to obtain a comparable sample size.

Two-tailed chi-squared tests were performed to detect statistically significant differences in the rates of out-of-range data between the old, the new, and the manual systems taken two at a time. In those cases where the value of any cell was 0 or the values in more than one cell were less than 5, two-tailed Fisher's Exact tests were performed instead.

RESULTS

Comparison of Medians and "Real-Time" Values

One hundred and seventy-five hours of data were collected from 28 STRICU patients. The data contained 702 quarter-hour median calculation times. The largest dataset contained 48 median calculation times, the smallest contained one, and the average per dataset was 21.9 calculation times.

The data allowed 698 comparisons between median systolic pressures and the actual "real-time" systolics recorded on the quarter-hour, 697 comparisons between median diastolics and "real-time" diastolics, and 696 comparisons between median mean arterial pressures and "real-time" means pressures. The numbers of comparisons were different for the various parameters and did not equal 702 because of occasional "missing" data in the datafiles. "Missing" datpoints resulted when errors occurred while writing to the minicomputer datafiles, when the Marquette monitor did not report values at quarter-hour times, and when medians were not calculated because fewer than three datapoints had been received during the previous 15 minutes. The results of the blood pressure and heart rate comparisons are shown in Table II. The comparison for temperature revealed that all 154 median temperatures compared were within 0.1 degree Celsius of the actual temperature sampled on the quarter hour.

Out-of-Range Values

The results of the Chi-squared and Fisher's tests are presented in Tables III through V.

DISCUSSION

The median system was found to report values that were usually in agreement with what was charted under the "real-time" system. In those cases where there were large differences, the median system reported a representative value while disregarding short-term transients. Figure 1 shows an example of a large discrepancy between values reported by the "real-time" and median systems. At 20:30, the systolic pressure value reported by the "real-time" system was 252 mm Hg. At 20:33, the reported systolic was 267 mm Hg. Also at 20:30 and 20:33, the diastolic pressures reported by the "real-time" system were 195 mm Hg and 210 mm Hg, respectively. All these values were almost surely artifactual. The median system at 20:30 reported a value of 119 mm Hg for systolic pressure and 69 mm

Table II. Discrepancies between values recorded by the "real-time" recording system and values recorded by the median recording system.

Parameter	Discrepancy (mm Hg or beats per minute)									
	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91+
Systolic (698 total)	606 (86.8%)	59 (8.5%)	17 (2.4%)	5 (0.7%)	5 (0.7%)	4 (0.6%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (0.3%)
Diastolic (697 total)	649 (93.1%)	33 (4.7%)	7 (1.0%)	1 (0.1%)	2 (0.3%)	1 (0.1%)	1 (0.1%)	1 (0.1%)	0 (0.0%)	2 (0.3%)
Mean (696 total)	641 (92.1%)	35 (5.0%)	8 (1.1%)	6 (0.8%)	3 (0.4%)	0 (0.0%)	1 (0.1%)	1 (0.1%)	0 (0.0%)	2 (0.3%)
Heart Rate (813 total)	772 (95.0%)	27 (3.3%)	10 (1.2%)	3 (0.4%)	0 (0.0%)	1 (0.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)

Table III. Out of range values in the "real-time" system v. in the median system.

Parameter	Out of Range Values/Total Values (%)		Statistically Significant?
	"Real-Time" System	Median System	
Systolic Pressure	71/6528 (1.09%)	23/6531 (0.35%)	yes (p=0.000001)
Diastolic Pressure	21/6528 (0.32%)	0/6520 (0.00%)	yes (p<0.000001)
Heart Rate	1/7720 (0.01%)	1/7037 (0.01%)	no (p>0.95)

Table IV. Out-of-range values in the median system v. in manual charting.

Parameter	Out of Range Values/Total Values (%)		Statistically Significant?
	Nurse Charting	Median System	
Systolic Pressure	87/6561 (1.33%)	23/6531 (0.35%)	yes (p<0.000001)
Diastolic Pressure	27/6552 (0.41%)	0/6520 (0.00%)	yes (p<0.000001)
Heart Rate	44/5197 (0.85%)	1/7037 (0.01%)	yes (p<0.000001)

Table V. Out-of-range values in the "real-time" system v. in manual charting.

Parameter	Out of Range Values/Total Values (%)		Statistically Significant?
	Nurse Charting	"Real-Time" System	
Systolic Pressure	87/6561 (1.33%)	71/6528 (1.09%)	no (p=0.2425)
Diastolic Pressure	27/6552 (0.41%)	21/6528 (0.32%)	no (p=0.4775)
Heart Rate	44/5197 (0.85%)	1/7720 (0.01%)	yes (p<0.000001)

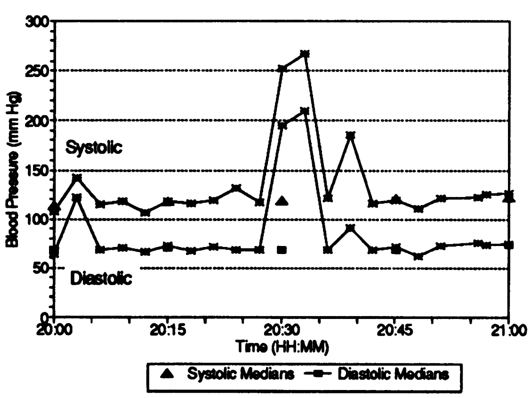

Figure 1. First example of a large discrepancy between medians and actual values. The "real-time" values at 20:30 are obviously artifacts.

Hg for diastolic pressure, which are much more reasonable values.

Figure 2 illustrates another large discrepancy between the two systems. At 11:45, the "real-time" system reported a systolic pressure of 245 mm Hg and a diastolic of 95 mm Hg. Again, these values were most likely artifactual. The median system reported values of 120 mm Hg for systolic pressure and 72 mm Hg for diastolic.

Figure 2 also illustrates a more problematic discrepancy, however. At 12:00, the systolic pressure reported by the "real-time" system was 181 mm Hg while the diastolic was 107 mm Hg. These values are high, but not in the physiologically impossible range. It is possible that they represent a true physiological event. Nevertheless, the median system in essence ignored them, reporting a systolic of 127 mm Hg and a diastolic of 77 mm Hg. This example may be perceived as a shortcoming of the system, unless the system's intended purpose is remembered. The system was designed to perform routine reporting, not exception charting. In other words, the exclusion of events such as the one at 12:00 is deliberate. Documentation of events falls under the jurisdiction of another reporting scheme (presently, manual charting). Admittedly, differentiating between a routine reporting system and an exception charting system requires the difficult demarcation of when a transient episode becomes sustained enough to be considered a trend. By choosing 15 minutes as the median width, we have implicitly made that demarcation.

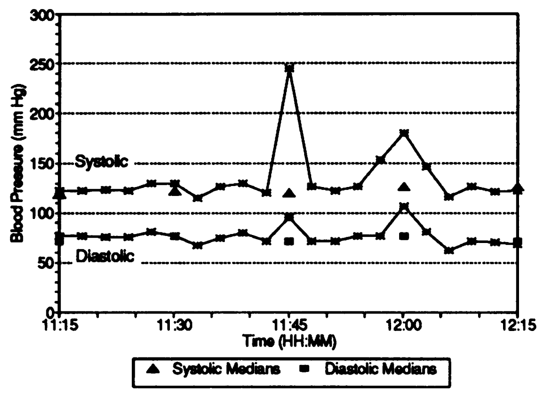

Figure 2. Second example of a large discrepancy between medians and actual values. The "real-time" values at 11:45 are probably artifacts, but the values at 12:00 may be real. Nevertheless, the medians report representative values for the 15 minute time periods.

The median system resulted in a statistically significant reduction in out-of-range systolic and diastolic pressures compared to both the "real-time" system and the nurses' manual charting. Even though the frequency of out-of-range values was not large before implementation of the median system, even a small frequency was enough to cause spurious data in the 24-hour Rounds Reports. Anecdotal evidence suggests that physicians are more satisfied with Rounds Report values since implementation of the median system. The system was implemented in LDS Hospital's other Intensive Care Units in October of 1993. Real-time values are no longer stored.

We expect that the most important gains resulting from the median system are yet to be realized. More accurate and representative data in the Rounds Report is an important accomplishment, but even more important are the expected benefits of being able to use the automatic monitoring data as inputs to other computerized applications. Now that blood pressures are more reliable, the hospital's computerized APACHE system has received renewed attention. Also, we are presently developing a protocol for the administration of sedatives and paralytics. We hope to be able to use automatically recorded blood pressures as an input to the protocol's decisions. In short, the benefits achieved by improving the representativeness of automatically charted vital signs emerge not just in a printout of a report today but in the freedom it allows us to pursue other more ambitious goals in the future.

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